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Stanford Industrial Park Palo Alto, California

ALFRED

MICROWAVE AMPLIFIER

MODEL 529 , Serial No. 22

FECL 8046

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MICROWAVE AMPLIFIER
MODELS 529, 529-S1

SPECIFICATIONS	Model 529	Model 529-S1
Frequency Range:	4 to 8 Gc.	4.8 to 6.5 Gc.
Gain (at rated power output):	30 db minimum.	27 db minimum.
Gain (small signal @ 0 dbm in):	35 db minimum.	30 db minimum.
Gain Adjustment:	0 to 25 db gain reduction at 0 dbm in by adjustment of front panel GAIN-POWER control from maximum to minimum.	
Power Output:	10 watts	
Spurious Modulation:	40 db minimum @ 0 dbm in.	
Modulation:	Greater than 25 db gain variation by 300 volts external pulse.	
RF Impedance:	50 ohms.	
Connectors:		
RF	Type N female receptacle, front panel.	
EXT MOD	Type BNC, front panel.	
Metering:	Helix current, and Collector current on 4" front panel meter, selected by front panel switch. Helix, anode, and cathode tip jacks are available at rear for checking with external precision voltmeter.	
Front Panel Controls:	GAIN-POWER (maximum to minimum setting). HELIX voltage (MIN. to MAX.) METER current switch.	
Power Supply:	All TW tube electrode voltages, and solenoid current are regulated. Protective relay shuts off TW tube power upon helix overcurrent.	
Input Voltage:	105 to 125 volts, 50/60 cps.	
Physical:	Bench, with perforated metal dust cover. Handle sides are removable to permit mounting in a standard 19" rack. Height: 12 1/4" Width: 19" Depth: 16" from panel, 17 1/2" overall.	
Finish:	Panel grey hammertone. Sides, top and bottom, dark metallic grey.	
Weight:	71 pounds.	

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SECTION 1 - GENERAL

1-1 DESCRIPTION

The ALFRED Model 529 Microwave Amplifier is a stable, high gain broadband power amplifier of microwave signals in the frequency range of 4 to 8 Gc. It is a compact, versatile instrument consisting of a permanent magnet type traveling wave tube, and power supplies for all required operating voltages. Electrical protection is provided to prevent damage to supply or TW tube from misadjustment or failures. Thus the varied and unique traveling wave tube characteristics may be conveniently applied to laboratory and systems use. Some possible applications are:

1. Power amplification of wide band signal generator outputs of complex modulated RF signals.

2. Amplification of RF pulses with rise times as short as a few millimicroseconds.

3. Isolation of a load from a microwave signal source.

4. Generation of extremely stable microwave oscillations either at fixed frequency or tunable over a wide range, using an external resonant feedback network.

Type N RF power connections can be made at either the front or rear panels. The unit is normally shipped with connectors mounted on the front panel. Rear connections are simply made by remounting the connectors and cables to holes provided in the rear panel.

Panel controls for grid and helix voltages are provided to optimize performance for specific applications. A panel meter with switch monitors either helix or collector current. An overcurrent relay causes shut off of all high voltage should helix current exceed 3 ma for any reason.

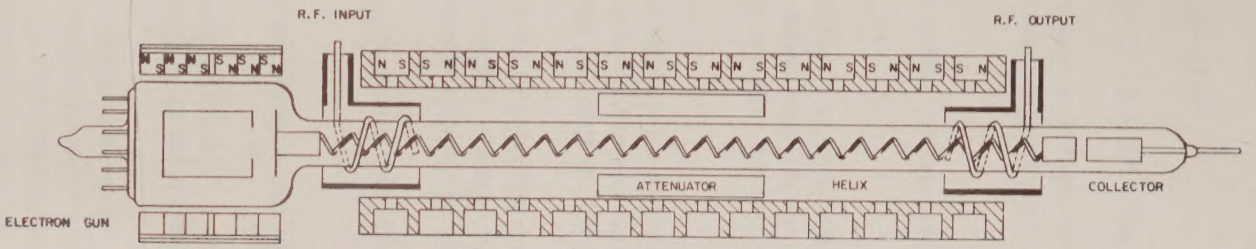
The TW tube requires no RF adjustment, is completely encased for protection, and is easily replaced.

The Model 529 is built as a convenient laboratory bench instrument. However, simply by removal of outside sheet metal sides, it may be mounted in a standard relay rack.

SECTION 2 - THEORY OF OPERATION

2-1 GENERAL DESCRIPTION OF TW TUBE

The traveling wave tube physical arrangement is indicated in Figure 1. The electron gun produces a beam of electrons which travels down the axis of the helical wire coil to the collector. The magnetic flux from the surrounding permanent magnet restricts the beam to travel axially along the tube just inside the helix. RF signals at low impedance are



PPM TRAVELING WAVE TUBE

FIGURE 1

connected to the helix at the electron gun end and travel down the metallic path of the helix. The velocity of the electron beam is critically adjusted by the potential difference of the cathode and helix so that the beam velocity down the axis is just a little faster than the progressive RF signal on the helix The field of the helix RF signals causes the electrons to bunch so that at the collector end, their increased field returns to the helix an amplified signal which is conducted out to the load. Reflections down the helix are absorbed by the attenuator, consisting of a lossy helix externally placed and positioned between the input and output. Due to the low impedance connections to the helix and the relatively long effective path provided by the TW tube, uniform amplification over a broad band of frequencies is achieved.

A more detailed description of traveling wave tubes and associated pertinent information are presented in the Engineering Notes, at the end of this manual.

2-2 TW TUBE PERFORMANCE CHARACTERISTICS

Gain and Power Output Figure 2 shows typical curves of small signal gain, and maximum power output as a function of frequency. These curves are taken at rated helix voltage. The small signal gain is better than 40 db over the frequency range. Gain at rated and saturated output is greater than 40 db over the same frequency range. Gain-Power attenuation is greater than 25 db by panel control of the grid voltage. Attenuation is greater than 25 db by an external 300 volt pulse to the grid through EXT MOD connector S1.

2-3 RF LOAD

The TW tube may be operated at any collector current up to rated value into an RF load with any voltage standing wave ratio in the rated frequency range. Performance will be stable without spurious oscillations, but output power will be less into mismatched loads.

2-4 POWER SUPPLY

1. A transistor regulated AC heater supply, insulated for full cathode DC voltage, providing 6.3 volts for the TW tube and the heaters of the control amplifier tubes.

2. An electronically regulated Helix, and Collector supply providing voltage from 2900 to 3200 volts with 320 mv peak to peak ripple or less.

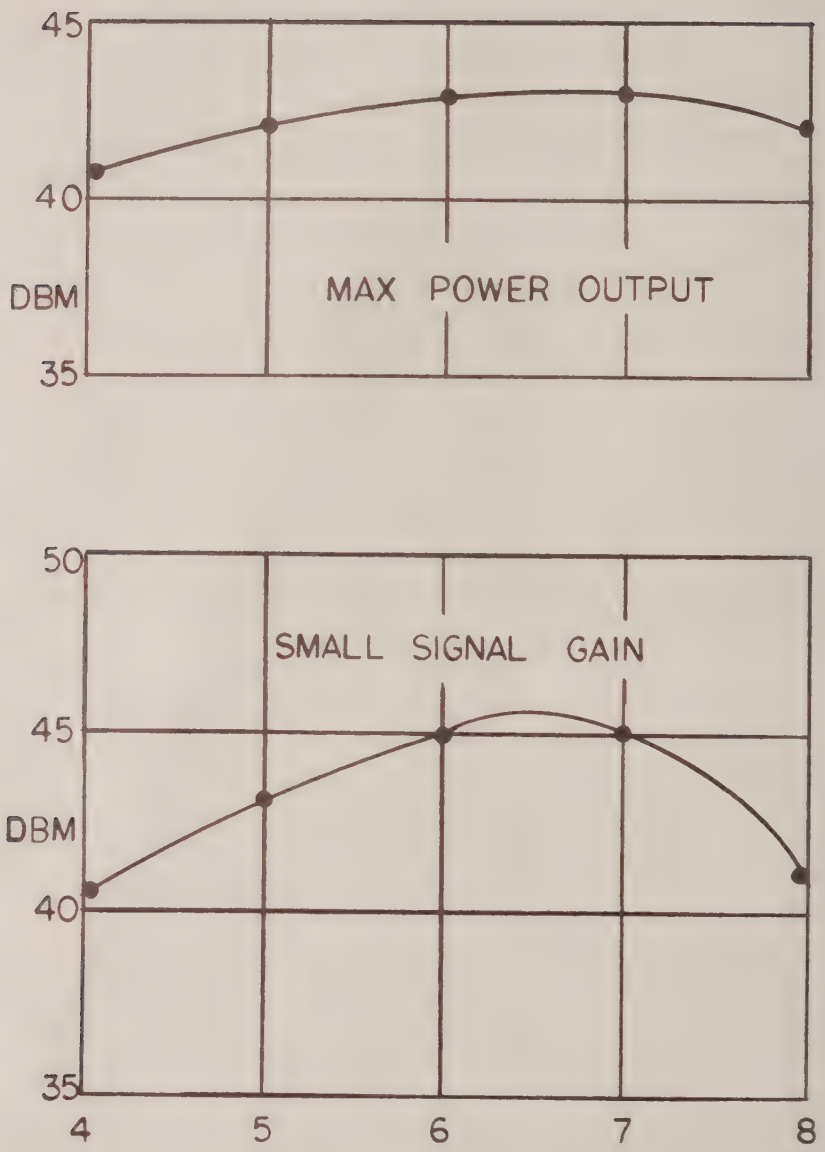
3. A transistor regulated Anode supply providing a fixed 54 volts above helix.

2-5 FUNCTION OF CIRCUITRY

Function of circuitry, see schematic in the rear of this manual. In this manual, reference to panel controls is made with capital letters and underlined, internal or chassis controls is made by capital letters only.

2-6 POWER AND SWITCHING

All power to the instrument is fed through POWER switch SW1. Closing of SW1 energizes



TYPICAL MODEL 529 POWER OUTPUT AND GAIN VS FREQUENCY

FIG. 2

transformer T1 and T3 through POWER fuse F2 to provide filament currents to the TWT and power supply heaters, the 300 volt grid supply, the 56 volt anode and screen supply, and the 200 volt supply required in the helix overcurrent relay K2 circuit. Helix overcurrent relay K2 picks up through tube V9 to place the unit in standby condition. The high voltage circuit powered by transformer T2 through fuse F1 and contacts of relays K1 and K2 may be energized by depressing HV ON switch SW3 to pick up relay K1. Interlock contacts on K1 maintain the circuit when SW3 is released. The high voltage supply is de-energized by depressing HV OFF switch SW2, should overcurrent relay K2 drop out due to excessive helix current.

2-7 LINE REGULATED SUPPLIES 6.3V, 300V, and 56V

Regulation of these supplies is accomplished by regulating the input to the primary of transformer T3. Transistor Q1 is effectively in series with the input transformer T3. Rectifiers CR2 to CR5 are connected in a bridge network to provide DC to the transistor for the positive and negative swings of the AC line. The voltage drop across the transistor automatically adjusts to maintain the primary voltage of T3 essentially constant, independent of line voltage changes. The drop across the transistor is varied by employing Zener diode ZD1 as a stable reference through which changes in output voltage control the net transistor base current. On one half cycle forward transistor emitter to base bias is developed through the 5K resistor R1 and the low forward diode resistance of the Zener. On the other half cycle the bias current is opposed by any output voltage in excess of the Zener breakdown voltage and is developed through the low forward diode resistance of CR1. Biasing is set so that variation of ± 10% maximum from nominal 115 volts rms input, will cause corrective changes in the drop across Q1 for less than ± 3% change in the output. Capacitor C1B serves to average the DC current pulses through the transistor and bypass any AC ripple. C1A operates in the same manner for the base bias current. Taps are provided on the transformer T3 primary to compensate for voltage tolerance of the Zener diode.

2-8 HIGH VOLTAGE SUPPLY

When transformer T2 is energized by depressing the HV ON switch, approximately 3800 volts DC is supplied to the series control tubes, V1, V2, and V3 in parallel from the voltage doubling network of capacitors C5 and C6, rectifiers CR8 to CR16, CR17 to CR25, and winding 1-2 of T2.

The series regulating tubes V1, V2, and V3 in parallel are controlled by amplifier tubes V4 and V5 to provide an electronically regulated supply with a nominal value to 3200 volts. Reference voltage is developed across V6, V7, and V8 and is compared with the supply output voltage at the grids of differential amplifier V5. The amplified difference at the plates of V5 is applied to the cathode and grid of the left half of V4 by employing the right half of V4 as a cathode follower. The difference voltage is further amplified and appears at the plate of V4 left half as a single ended output to drive the grids of the series regulator tubes V1, V2, and V3. The series tubes will conduct more or less as required to reduce the difference in grid voltages to the differential amplifier V5 to zero and thereby maintain the supply output at 3200 volts.

The supply voltage is sampled by a resistor divider network consisting of HELIX CALIB potentiometer R32 and precision resistors R33 through R40 to provide the input to grid (pin 2) of

differential amplifier V5.

The positive side of the supply is connected to ground through meter M1 resistor R63. The capsule and collector of the TW tube are connected to the ground side and the cathode to the -3200 volt side of the supply.

Helix voltage is obtained from the left half or pentode side of V9 acting as a cathode follower. The grid of V9 (pin 7) is connected to front panel HELIX control potentiometer R47 and can be varied from approximately +3 to -400 volts with respect to ground or conversely from +2800 to +3200 volts with respect to TWT cathode. The plate voltage of V9 left half is supplied by T2 winding 4-5 through rectifier CR7 and filter capacitor C4.

HELIX CALIB potentiometer R32 provides compensation for component tolerance variations so that accurate calibration of HELIX control potentiometer R47 can be made.

Helix current through R60 varies the bias on tube V9 right half. When the helix current reaches maximum safe value, the bias is increased sufficiently to cut off the tube and drop out overcurrent relay K2. Contacts of K2 open the high voltage circuit to remove all high voltages from the TWT electrodes Voltage for the plate of V9 right half and K2 in series is provided by transformer T1 winding 3-4 through resistor R2, rectifier CR6 and filter capacitor C3.

Filaments of series tubes V1, V2 and V3 are connected in series so that failure of one will turn off all and prevent overloading of operative tubes. Heaters of amplifier tubes V4, V5 and overcurrent relay tube V9 are also connected in series so that open circuit on any heater will turn all off, dropping out relay K2 and removing high voltage.

A fixed voltage of approximately 56 volts above the helix voltage (less the small drop due to helix current in R60) is supplied by the +56 volt supply. The +56 volt supply also furnishes the screen voltage for V9 pentode side.

Helix, Anode, and Cathode tip jack connections are provided on the rear of the instrument for external voltage measurements.

Switch SW4 selects either Collector or Helix current to be measured with meter M1. Shunts R63 and R65 provide scale multiplication. During the switching action of SW4 only the meter connections are broken, the shunts remain in their respective circuits so that neither the collector nor the helix circuits are broken during switching.

2-9 EXTERNAL PULSE MOD AND GRID CONTROL

Transformer T3 winding 1-3, diodes CR27 and CR28, capacitors C22 and C23 form a voltage doubling network to provide -300 volts relative to the TWT cathode line. GRID CALIB potentiometer R71 in series with GAIN-POWER control R72 across the supply furnish a variable grid voltage of 0 to approximately -300 volts which is connected to the grid through resistor R73. The GRID CALIB potentiometer R71 provides a range of 0 to -50 volts to permit the setting of the grid electrode voltage at correct value for maximum power output when the GAIN-POWER control is at MAX position.

Both the gain and the power output of a TWT amplifier are dependent upon beam current which in turn may be controlled by the grid electrode voltage. For this reason the grid control potentiometer R72 is marked GAIN-POWER and is panel mounted for ease of operation.

SECTION 3 - INSTALLATION AND OPERATION

3-1 INSTALLATION

Upon receipt carefully unpack and inspect the instrument for damage received from transit. Should any damage be found, follow procedure outlined on "Shipment Damage Claim" page at the end of this manual.

This instrument is designed for either bench or rack operation in normal ambient temperatures. Air flow near the unit should be completely unrestricted. Operation in the presence of very strong magnetic fields should be avoided unless external magnetic shielding is provided. Primary power requirements are 105 to 125 volts, 50 to 60 cps, approximately 500VA. If operation at other voltage or frequency is contemplated, consult manufacturer.

The Model 529 instrument is supplied with grey sheet metal sides containing handles. If the instrument is to be rack mounted, the screws on each handle side except those holding handle, should be taken out and the sides removed. Unit is now ready for inserting into rack. Supports should be provided in the rack to carry the weight of the unit upon its insertion or removal.

CAUTION: The ambient temperatures in the rack near the instrument must be maintained at less than 135° F.

3-2 INITIAL OPERATION

1. Before turning on power, set panel controls:

   GAIN-POWER to MIN.
   HELIX to V.
   METER switch to HELIX

2. Turn on power and allow instrument to warm up at least 5 minutes.

3. Depress HIGH VOLTAGE ON switch.

4. Slowly advance GAIN-POWER control to MAX position. Note that as the control is advanced, helix current should be well below 3 ma.

5. When GAIN-POWER control has been advanced to MAX and HELIX to value specified on tube data sheet with helix current at or below its maximum value, change METER switch to COLLECTOR X20. Current should be at or slightly greater than the operating value of cathode current given on the TW tube data sheet enclosed at the rear of this manual.

If current reading is too low GRID CALIB control near top right side of chassis may require resetting. Remove top dust cover for access to control.
CAUTION: Extremely dangerous voltages exist on and near this adjustment. Use extreme care in making the adjustment not to touch any component or hardware mounted on the high voltage board. Turn HIGH VOLTAGE off before loosening or tightening the lock nut on the control. Use a plastic rod with one end shaped to a screw driver point to make the adjustment. Adjust until rated cathode current given on tube data sheet is obtained, alternately checking helix current to assure it remains below maximum value.

6. Apply RF. Input power up to 1 watt will not cause damage. However, only the normally required level of a few milliwatts or less should be used. If RF output can be observed, adjust, if necessary, HELIX voltage slightly for optimum output. See also sub-section following, titled SYNCHRONISM. If RF output cannot be measured, connect an ungrounded 1/2% or better accuracy voltmeter to read helix voltage between HELIX and CATHODE tip jacks at rear of instrument and set HELIX control to give a measured voltage of exactly that specified on TW tube data sheet.

7. METER switch should be left in COLLECTOR X20 position during normal operation. An occasional check of helix current is recommended.

3-3 SYNCHRONISM

When the velocity of the electron stream and the progressive velocity of the RF signal are essentially the same, they are said to be in SYNCHRONISM. When operation at a single frequency is contemplated, helix voltage can be adjusted to synchronous value, to give maximum gain and output at that frequency. When operation over a wide band of frequencies is contemplated, the helix voltage adjustment should be made to the factory determined value. At this setting synchronism usually occurs at some frequency usually near the high end of the band. Even though other frequencies are off synchronism, rated broadband response results.

3-4 REPEAT OPERATION

1. Before turning on power, turn GAIN-POWER control to min.

2. Turn on power and allow 5 minutes warmup.

3. Depress HIGH VOLTAGE ON switch and raise GAIN-POWER control to MAX, or to desired operating level, noting that helix current does not exceed 3 ma and should drop well below this at MAX position. If too high, turn GAIN-POWER to MIN and follow procedure outlined in INITIAL OPERATION, Paragraph 3-2 above, to optimize performance.

3-5 OPERATION AS AN AMPLIFIER

Amplification is linear for RF output up to 6 db below saturation. Further drive beyond this level causes the output to flatten and then decrease. Operation in the region of saturated output is nonlinear, causing appreciable distortion and harmonic content in the output signal.

3-6 OPERATION AS A BUFFER

The Model 529 can very effectively serve to isolate a microwave signal source from a load. Reflections from mismatches, load variations, and the effects of modulation will not appreciably affect the impedance of the input terminals of the amplifier. The attenuator on the TW tube helix provides approximately 55 db attenuation between input and output, so load changes will be isolated from the source by this 55 db attenuation less the gain of the amplifier. The extreme case of a short or open circuit would be to change the VSWR of the amplifier input by about 7%.

3-7 OPERATION AS AN OSCILLATOR

The use of an external feedback circuit involving a passive resonator such as a cavity, will permit use of the TW tube amplifier as an extremely stable fixed frequency or wide range oscillator. Oscillation results when total loop phase shift is in the vicinity of n x 360° producing positive feedback. This is accomplished by careful adjustment of helix voltage. Since helix voltage accelerates the electrons in the beam, it determines their velocity through the helix. Transit time and phase between output and input of the TW tube, therefore, varies with helix voltage. When a continuously adjustable resonator is employed, it is necessary to optimize phase with the HELIX control progressively across the band. Otherwise, a series of oscillation modes will occur as phase of the TW tube amplifier rotates. A directional coupler or non-dissipative attenuator should be employed in the feedback line to minimize amount of output power fed to the input. This reduces harmonics and makes available almost all output power to drive a load.

SECTION 4 - MAINTENANCE

4-1 GENERAL

CAUTION: Extremely dangerous high voltages exist in this instrument. Observe the utmost care when checking or making repairs.

Routine maintenance should consist of the following:

1. Check blower operation every three months or after 1000 hours use, and oil bearings with a few drops of light machine oil. Regular attention to the blower is essential since its failure could result in damage to the TW tube from overheating.
2. Test at regular intervals the power supply tubes to detect marginal performance. Any voltage regulator tubes removed for test should be returned to their original sockets. INTERCHANGING OR REPLACING VOLTAGE REGULATOR TUBES WILL NECESSITATE RECALIBRATION OF HELIX SUPPLY VOLTAGE.

3. As the TW tube ages, preset GRID CALIB control may require readjustment to maintain rated collector current when panel GAIN-POWER control is at MAX.

4-2 CALIBRATION OF HELIX SUPPLY VOLTAGE

Calibration of helix supply voltage is accomplished by connecting an ungrounded voltmeter having 1/2% accuracy or better to the Helix Voltage test points on rear of the unit. Unlock the HELIX CALIB control, located near the right top side of chassis. With TWT disconnected, move panel HELIX control over entire range and note readings. Adjust HELIX CALIB control so that voltage indications are within ±2% for any setting. Lock HELIX CALIB control.

4-3 TROUBLE SHOOTING

Should a failure occur, follow a logical procedure to locate the cause. Refer, if necessary to the THEORY OF OPERATION section and the schematic diagram included in this manual. Blown fuses should be replaced with 250 volts, type 3AG.

Power supply tubes can be observed to determine if heaters are operating and voltage regulator tubes lit, by removing screws holding top dust cover and sliding it rearward. Operating voltages for the traveling wave tube may be measured as described below. Various circuit voltages are indicated on the schematic.

Helix: Helix and Anode voltages relative to cathode are available at tip jacks on rear cover. CAUTION: Use high resistance, ungrounded DC voltmeter, HIGH VOLTAGES EXIST ON TERMINALS.

The Grid and Heater voltages may easily be checked at terminal strip TS1. Use a high resistance DC voltmeter insulated from ground in making measurements. Refer to the schematic diagram and check out sheets for correct values and polarity.

If tubes have been tested and found to be normal, and supply voltages are incorrect, it is recommended that power be disconnected and faulty components located by a systematic resistance check.

For access to chassis components remove right handle side and cover side. CAUTION: Use heat sinks during soldering operations on transistors and diodes.

4-4 BLOWER REPLACEMENT

Remove dust screen, L. H. handle and cover sides, remove four mounting screws (6-32).

Unsolder blower leads. Blower may now be removed. In reassembly follow reverse procedure.

4-5 TRAVELING WAVE TUBE REPLACEMENT

1. Remove top dust screen.

2. Disconnect RF connectors from TWT.
3. Disconnect TWT electrode leads from terminal strip TS1.
4. Remove L. H. handle and cover side.
5. Remove four mounting screws holding TWT to deck and remove tube.
6. Follow reverse procedure in installing new tube.

4-6 OPERATION AFTER TWT REPLACEMENT

After the replacement of the TWT only the GRID CALIB control will need readjustment.

1. Before turning on power, set panel controls:

   GAIN-POWER to MIN
   HELIX to value stated on new tube data sheet
   METER switch to HELIX

2. Turn on power and allow instrument to warm up at least five minutes.
3. With High Voltage OFF , turn GAIN-POWER to MAX and set grid voltage with GRID CALIB control to value stated on new tube data sheet. May be measured between terminals 4 and 7 on terminal strip TS1.
4. Now proceed as in INITIAL OPERATION, Paragraph 3-2.

4-7 TRAVELING WAVE TUBE WARRANTY

See Tube Warranty and Replacement Procedure sheet at rear of manual.

4-8 WARRANTY

ALFRED products are warranted against defects in workmanship and materials. This warranty is limited to repair or replacement of products or parts (except tubes, transistors, and batteries) which prove defective within one year after delivery to original purchaser. ALFRED ELECTRONICS is not liable for consequential damage.

MICROWAVE AMPLIFIER

MODEL 529, Serial No. 22

GRID @ 115 V INPUT TS1 Term. 7 to Chassis, TS1 Term. 4 shorted to chassis. Remove High Voltage Fuse

Gain-Power Max., H.V. off E Min (< 1) Volt

Gain-Power Max., H.V. off E Max (> 55) Volts — Ripple (< 25) mv pk to pk

Gain-Power Min., H.V. off E Max (> 300) Volts @ 103 V input — Ripple (< 1) V pk to pk

Gain-Power Min., H.V. off E Max (< 6) V Change from 103 to 127 volts input

Remove Jumper from Term. 4

COLLECTOR @ 103 Volts Input TS1 Term. 4 to Chassis

Collector @ 60 ma E (3136 - 3264) Volts — Ripple (< 300) mv pk to pk

HELIX @ 115 V Input TS1 Term. 2 to TS1 Term. 4

Helix @ 2800 V (min), Collector @ 60 ma — E min (2744 - 2856) V
Ripple (< 300) mv pk to pk

Helix @ 3200 (max) V, Collector @ 60 ma — E max (3136 - 3264) V
Ripple (< 300) mv pk to pk

Overcurrent Relay Trips @ (2.7 - 3.3) ma

ANODE @ 115 Volts Input TS1 Term. 3 to TS1 Term. 4 No load

Helix @ 2800 (min) V, Collector @ 60 ma — E min (2800 - 2912) V
Ripple (< 1) V pk to pk

Helix @ 3200 (max) V, Collector @ 60 ma — E max (3192 - 3320) V
Ripple (< 1) V pk to pk

HEATER TS1 Term. 5 to TS1 Term. 6 CAUTION HIGH VOLTAGE

103 Volts input E (6.0 - 6.6) V AC @ 0.4 amps

ΔE (< .6) V Change from 103 to 127 volts input

Checked By Date

MODEL 529-S1

Serial No. ____

GRID @ 115 Volts Input TS1 Term. 7 to chassis, TS1 Term. 4 shorted to chassis. Remove High Voltage Fuse.

Gain-Power Max, H.V. OFF E min (< 1) V

Gain-Power Max, H.V. OFF E max (> 55) V Ripple (< 25) mv pk to pk

Gain-Power Min, H.V. OFF E max (> 300) V @ 103 V input
Ripple (< 1) V pk to pk

Gain-Power Min, H.V. OFF E max (< 6 volt change) from 103 to 127 volts input
Remove jumper from Term. 4

COLLECTOR @ 103 Volts Input TS1 Term. 4 to chassis.

Collector @ 60 ma E(2842-2958) V Ripple (< 300) mv pk to pk

HELIX @ 115 Volts Input TS1 Term. 2 to TS1 Term. 4

Helix @ min, collector @ 60 ma Emin (2548-2652)V
Ripple (< 300) mv pk to pk

Helix @ max, collector @ 60 ma E max (2842-2958) V
Ripple (< 300) mv pk to pk

Overcurrent relay trips @ (2.7 - 3.3) ma

ANODE @ 115 Volts Input TS1 Term. 3 to TS1 Term. 4 No Load

Helix @ min, Collector @ 60 ma E min (2604-2708) V
Ripple (< 1) volt pk to pk

Helix @ max, Collector @ 60 ma E max (2898-3014) V
Ripple (< 1) volt pk to pk

Helix @ max, Collector @ 60 ma 103 to 127 volts input

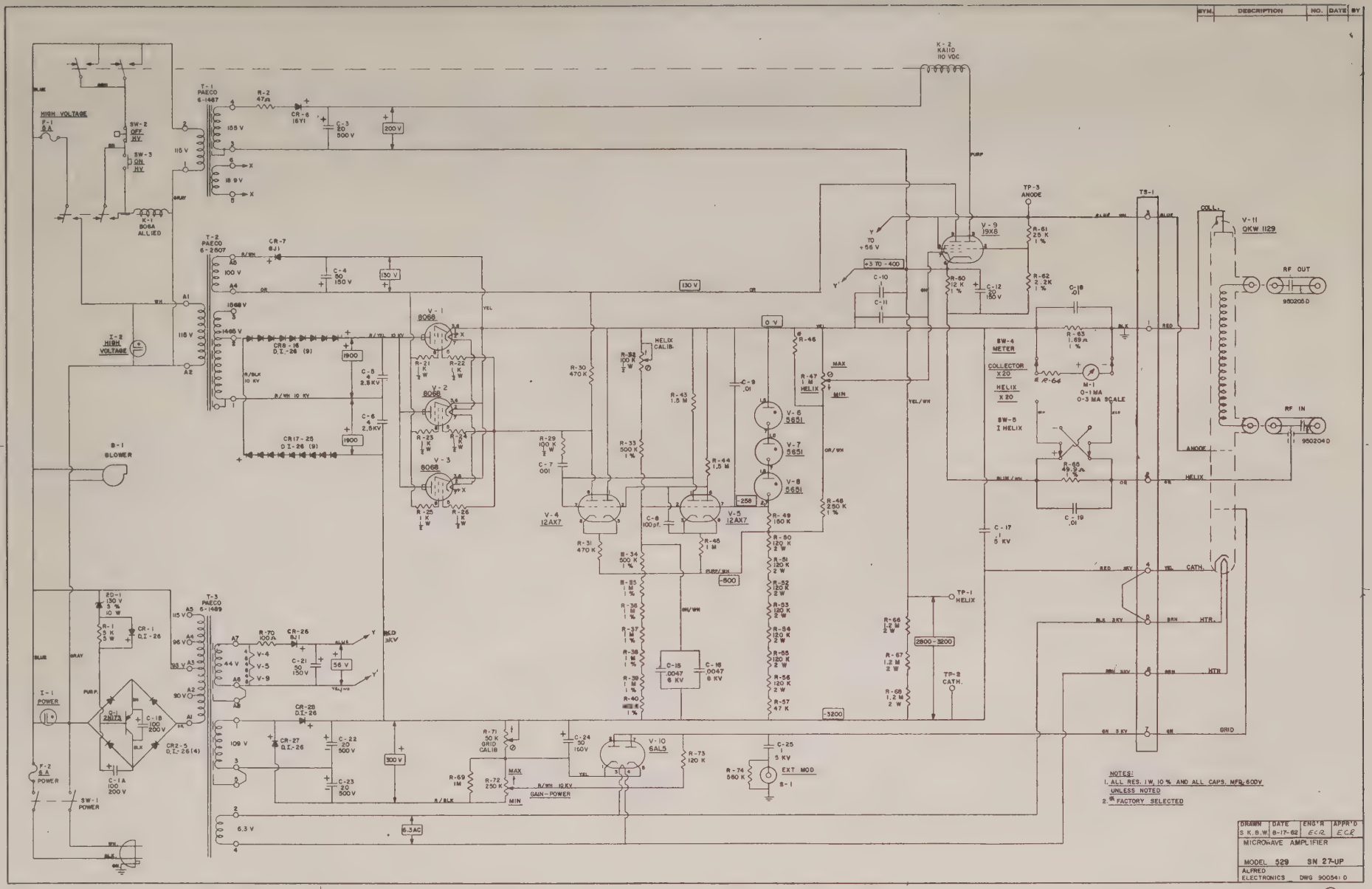
ΔE (< 10) volts change

HEATER TS1 Term. 5 to TS1 Term. 6 High Voltage OFF

103 volts input E(6.0 - 6.6) volts RMS @ 0.4 amps RMS

ΔE (< .6) volts change from 103 to 127 volts input

Checked By_____ Date _____


SYM. DESCRIPTION NO. DATE BY
K-2 KA110 110 VDC
HIGH VOLTAGE
SW-2 OFF/ 10V
SW-3 ON/ 10V
K-1 BOSA ALLIED
T-1 PAECO 6-1467
R-2 47Ω
CR-6 16Y1
C-3 20 500 V
200 V
115 V
18 9 V
T-2 PAECO 6-2507
CR-7 8J1
C-4 50 150 V
130 V
100 V
1568 V
1466 V
CR8-16 D1-26 (9)
1900
C-5 2.5KV
C-6 2.5KV
CR17-25 D1-26 (9)
I-2 HIGH VOLTAGE
B-1 BLOWER
V-1 8068
V-2 8068
V-3 8068
R-21 1K 1/2W
R-22 1K 1/2W
R-23 1K 1/2W
R-24 1K 1/2W
R-25 1K 1/2W
R-26 1K 1/2W
R-30 470 K
R-31 470 K
R-33 500 K 1%
R-34 500 K 1%
R-35 1 M 1%
R-36 1 M 1%
R-37 1 M 1%
R-38 1 M 1%
R-39 1 M 1%
R-40 1 K 1%
HELIX CALIB.
R-43 1.5 M
R-44 1.5 M
R-45 1 M
C-7 .001
C-8 100 pf.
C-9 .01
R-46
R-47 1 M HELIX
MAX
MIN
R-48 250 K
V-4 12AX7
V-5 12AX7
V-6 5651
V-7 5651
V-8 5651
-258
-800
R-49 150 K
R-50 120 K 2 W
R-51 120 K 2 W
R-52 120 R 2 W
R-53 120 K 2 W
R-54 120 K 2 W
R-55 120 K 2 W
R-56 120 K 2 W
R-57 47 K
-3200
C-15 .0047 6 KV
C-16 .0047 6 KV
C-17 5 KV
TP-1 HELIX
TP-2 CATH.
2800 - 3200
R-66 1.2 M 2 W
R-67 1.2 M 2 W
R-68 1.2 M 2 W
TP-3 ANODE
V-9 19X8
R-61 25 K 1%
R-62 2.2K 1%
R-60 12 K 1%
C-12 20 150 V
C-10
C-11
+3 TO -400
0 V
130 V
0 TO +56 V
C-18 .01
R-63 1.69 M 1%
R-64
M-1 0-1 MA 0-3 MA SCALE
SW-4 METER
COLLECTOR X20
HELIX X20
SW-5 I HELIX
R-65 49.9 Ω 1%
C-19 .01
T8-1
COLL.
V-11 QKW 1129
RF OUT
950205D
RF IN
950204D
ANODE
HELIX
CATH.
HTR.
GRID
D-1 130 V 5% 10 W
R-1 1K 5 W
CR-1 D1-26
I-1 POWER
D-1 22173
C-18 100 200 V
CR2-5 D1-26(4)
C-1A 100 200 V
F-2 8A POWER
SW-1 POWER
T-3 PAECO 6-1489
R-70 100 A
CR-26 8J1
C-21 50 150 V
56 V
V-4
V-5
V-9
CR-28 D1-26
CR-27 D1-26
C-22 20 500 V
C-23 20 500 V
109 V
300 V
6.3 V
6.3AC
R-71 50 K GRID CALIB
R-72 250 K
R-69 1M
MAX
MIN
GAIN-POWER
C-24 50 160 V
V-10 6AL5
R-73 120 K
R-74 560 K
C-25 5 KV
EXT MOD
S-1
NOTES:
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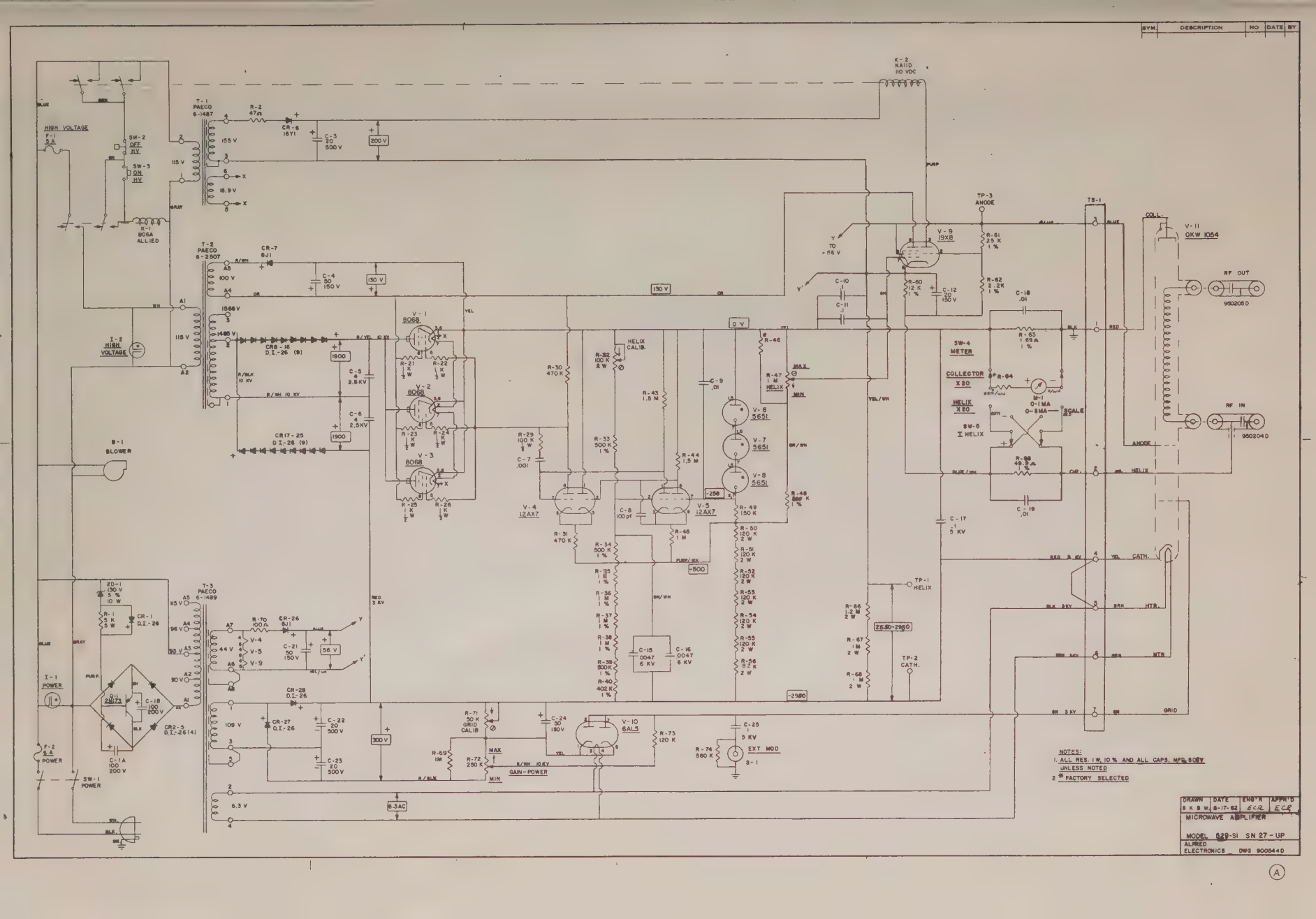
2. % FACTORY SELECTED
DRAWN S.K.B.W. DATE 8-17-62 ENG'R ECR APPR'D ECR
MICROWAVE AMPLIFIER
MODEL 529 SN 27-UP
ALFRED ELECTRONICS DWG 900541 D
A


SYM. | DESCRIPTION | NO | DATE | BY
HIGH VOLTAGE
F-1 5A
SW-2 OFF HV
SW-3 ON HV
K-1 8054 ALLIED
T-1 PAECO 6-1487
R-2 47Ω
CR-6 1671
C-3 20 500 V
200 V
115 V
155 V
16.9 V
K-2 KAIID 110 VDC
T-2 PAECO 6-2507
CR-7 BJ1
C-4 50 150 V
130 V
100 V
1568 V
1488 V
I-2 HIGH VOLTAGE
CR8-16 D.I.-26 (9)
CR17-25 D.I.-26 (9)
1900
C-5 .4 2.5KV
C-6 .4 2.5KV
B-1 BLOWER
V-1 8068
V-2 8068
V-3 8068
R-21 1K 1/2W
R-22 K 1/2W
R-23 1K 1/2W
R-24 K 1/2W
R-25 1K 1/2W
R-26 K 1/2W
R-30 470 K
R-32 100 K 2W
HELIX CALIB.
R-43 1.5 M
C-9 .01
R-46
R-47 1M HELIX
MAX
MIN
0 V
-250
-800
-2980
V-4 12AX7
V-5 12AX7
R-29 100 K 1/2W
C-7 .001
C-8 100 pf
R-31 470 K
R-33 500 K 1%
R-34 500 K 1%
R-35 1M 1%
R-36 1M 1%
R-37 1M 1%
R-38 1M 1%
R-39 500 K 1%
R-40 402 K 1%
R-44 1.5 M
R-45 1M
V-6 5651
V-7 5651
V-8 5651
R-48 2M K 1%
R-49 150 K
R-50 120 K 2W
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R-54 120 K 2W
R-55 120 K 2W
R-56 82 K 2W
C-15 .0047 6 KV
C-16 .0047 6 KV
C-17 .1 5 KV
R-66 1.2 M 2W
R-67 1M 2W
R-68 1M 2W
TP-1 HELIX
2550-2950
TP-2 CATH.
TP-3 ANODE
V-9 19X8
R-60 12 K 1%
R-61 25 K 1%
R-62 2.2K 1%
C-10
C-11
C-12 50 150 V
C-18 .01
C-19 .01
R-63 1.69A 1%
R-64
M-1 0-1 MA 0-8 MA
SCALE
R-65 49.9 A 1%
SW-4 METER
COLLECTOR X20
HELIX X20
SW-5 HELIX
T8-1
COLL.
V-11 QKW 1054
RF OUT
9502050
RF IN
9502040
ANODE
HELIX
CATH.
HTR.
GRID
Y
TO +56 V
Y'
T-3 PAECO 6-1489
ZD-1 130 V 5% 10 W
R-1 5 K 5 W
CR-1 D.I.-26
D-1 2W173
C-18 100 200 V
CR2-5 D.I.-26 (4)
C-1A 100 200 V
F-2 5A POWER
SW-1 POWER
I-1 POWER
R-70 100 A
CR-26 BJ1
C-21 50 150 V
56 V
V-4
V-5
V-9
CR-28 D.I.-26
C-22 20 500 V
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R-72 250 K
R-59 1M
MAX
MIN
GAIN-POWER
C-24 50 150 V
V-10 6AL5
R-73 120 K
R-74 560 K
C-25 .1 5 KV
EXT MOD
J-1
6.3 V
6.3 AC
NOTES:
1. ALL RES. 1W, 10 % AND ALL CAPS. MFD, 600V UNLESS NOTED
2. * FACTORY SELECTED
DRAWN B K B W. | DATE 8-17-62 | ENG'R ECR | APPR'D ECR
MICROWAVE AMPLIFIER
MODEL 629-SI SN 27 - UP
ALFRED ELECTRONICS
DWG 900644D
A

Freq. in Gc	Gen. Calib. DB	S. S. Gain Spec.	Max. Power Spec.	Rated Power Spec.	Spurious Mod. Spec.	Max. Helix I Spec.	Max. Power I Spec.
		> db Gc	> db Gc	> db Gc	> db	< μa ma	< μa ma
		> db Gc	> db Gc	> db Gc			

	Line Voltage			Line Voltage			Line Voltage			Line Voltage			Line Voltage			Line Voltage		
	105	115	125	105	115	125	105	115	125	105	115	125	105	115	125	105	115	125

*Grid Control > db Spec. > db Sweep Check OK

Vernier Control > db Spec. > db Helix Mod. OK

Helix V @ SSG V @ sat. Grid Mod. OK

Solenoid (Model No.)

Serial No.

PeT Tube

Serial No. (cathode)

Remarks: Gun mod very grassy but within spec

FECC 3046

*Check at ends and center of band, record worst readings.

Date

Calib. Eng.

K-2
KAITU
110 VDC

T-2
PAECO
6-2507

T-3
PAECO
6-1489

T-1
ANODE

V-10
QKW 1129

RF OUT
95X265D

RF IN

I-2
HIGH
VOLTAGE

B-1
BLOWER

I-1
POWER

SW-1
POWER

SW-2
HV

SW-3
HV

SW-4
METER

V-1
8068

V-2
8068

V-3
12AX7

V-4
12AX7

V-5
12AX7

V-6
6AL5

V-8
5651

V-9

Q-1
2N173

CR1-26
D1-26 (9)

CR2-5
D1-26 (4)

CR-1
D1-26

CR-2
D1-26

CR-7
D1-26

CR-8
D1-26

CR-9
D1-26

ZD-1
130 V
5 %
10 W

COLLECTOR
X20

GRID
CALIB

MAX

MIN

GAIN-POWER

EXT. MOD

S-1

TP-1
HELIX

TP-2
CATH.

TP-3
HELIX

-3200

-2800

-500

NOTES:
1. ALL RES. 1 W, 10 % AND ALL CAPS MFD, 600V UNLESS NOTED
2. * FACTORY SELECTED

DRAWN	DATE	ENGR	APPR'D
S.K.S.W.	8-17-62		

MICROWAVE AMPLIFIER

MODEL 529 SN 18-24

ALPHA ELECTRONICS DWG. NO. 2541-D

HUGGINS LABORATORIES
ENGINEERING NOTES
VOL. I, NO. 1 JANUARY, 1955
Published by Huggins Laboratories Sunnyvale, California

GENERAL INFORMATION ON TRAVELING-WAVE TUBES

R. A. Huggins*

Engineers who design circuits which use conventional low frequency vacuum tubes usually have at least a speaking acquaintance with their theory of operation. In designing circuits, or in deciding which type of tube to use, careful use is made of the various characteristic curves associated with these tubes. The following discussion will similarly acquaint the applications engineer with the simple theory of the operation of the traveling-wave tube and familarize him with the various characteristic curves which describe its operation.

MICROWAVE AMPLIFICATION

As the microwave region of the radio frequency spectrum came into practical engineering use, devices were needed which could function as better amplifiers and oscillators. Above a few hundred megacycles conventional vacuum tubes no longer amplify properly because the period of one cycle of the radio frequency wave approaches the time it takes the electrons to travel from cathode to anode. As a result the amplification factor of the tube decreases with increasing frequency until no useful gain can be obtained. This is known as the transit time effect.

The first device which served as a practical amplifier above a few hundred megacycles actually made use of the transit time effect. This device, known as a klystron, became useful primarily as an oscillator. The klystron, however, is also capable of acting as an amplifier. Klystron amplifiers are capable of giving high values of amplification, but they have two serious limitations for many applications: They are relatively narrow band devices which usually have no more than a few megacycles bandwidth between half-power points, and tuning the amplifier to different frequencies requires a mechanical adjustment. The klystron is, however, the forerunner of a general class of microwave electron devices which utilize transit time effects in electron beams. This general class of devices includes the traveling-wave tube (TWT).

A klystron is a narrow band device because it involves the use of a very sharply resonant, high-impedance tuned circuit. It is necessary for a klystron to use such a circuit because interaction takes place with the electrons over very short physical distances, and it must develop high electric fields to have efficient interaction with the electrons. It was reasoned, however, that one might obtain a very broadband amplifying device by using a low-impedance, broadband circuit which developed relatively small electric fields that interacted with the electrons over a long physical distance. Such is the basis on which the traveling-wave tube works, and this basic concept led to a wide range of devices which are useful as broadband amplifiers and oscillators in the microwave region.

The traveling-wave tube yields high values

* President, Huggins Laboratories, Inc.

of amplification over wide frequency ranges with no mechanical tuning mechanism or variation of any voltages or currents applied to the tube. Power amplification greater than 10,000 (i.e., 40 db gain) over a 2:1 frequency range has been obtained with this type of tube. The actual number of megacycles covered by such tubes can be a staggering figure. For example, an operating bandwidth of 2000 megacycles has been obtained in one typical tube type; 7000 megacycles has been obtained in another.

Tubes can be designed to emphasize various special characteristics. For instance, tubes are built which have low noise properties, high power output, or controlled variations of gain with frequency. Many special tubes are designed and built for particular applications.

FORWARD-WAVE HELIX TYPE AMPLIFIER

Among the simplest circuit elements which satisfy the broadband low-impedance circuit requirement of the traveling-wave tube is a simple helical transmission line. On this so-called helix, the radio frequency energy essentially travels at the velocity of light along the wire from which the helix is wound. Since the wire and the energy follow this helical path, progress of the energy along the axis of the helix is at some fraction of the velocity of light. This velocity is determined by the geometry of the helix (i.e., circumference and pitch) and by the dielectric loading due to the structure which supports the helix. The fields associated with this "slow-wave" extend outward and inward into the region adjacent to the helix, and it is into this region that electrons are sent to interact with the waves.

If electrons are directed along the axis of the helix at essentially the same velocity as the waves, an interaction between the waves and electrons occurs wherein the electrons become bunched. As the electrons progress along the axis they become packed into tighter and tighter bunches. Simultaneously, the radio frequency fields on the helix increase in magnitude as they progress down its length. The increase in energy of this "growing wave" is just balanced by a decrease in the average kinetic energy of the electrons in the beam. In other words, the electrons, on the average, have been slowed down and have given up just enough energy to account for the increasing energy or power level in the waves on the helix.

In practice, the electron beam is formed by an electron gun and focused down the center of the helix to a collector electrode at the farther end (see Figure 1). The electron beam is maintained in a tight pencil beam throughout the length of the tube by the confining forces of a longitudinal magnetic field which surrounds the tube. Electron velocity is determined by the voltage difference between the cathode in the electron gun and the helix, and this voltage difference is ad-

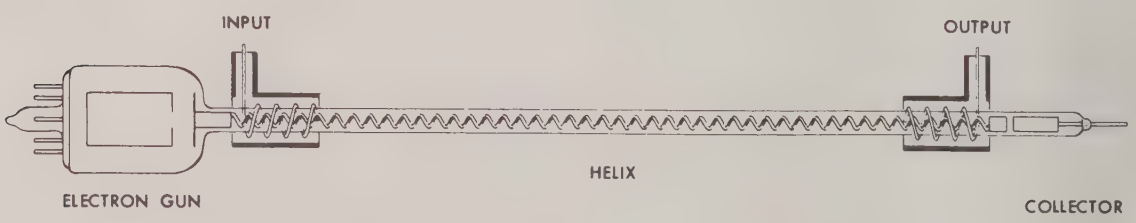

Figure 1. Schematic View of a Traveling-Wave Tube.

justed to give the electrons the right velocity for interaction with the waves. The signal to be amplified is coupled onto the end of the helix nearest the electron gun and propagates along the helix in the same direction as the electron beam. Because of the interaction, the fields on the helix grow exponentially with distance, and these amplified waves are coupled off the helix at the end farthest from the electron gun.

The devices which couple the energy onto and off the helix are special directional couplers which are in themselves helices. These helices are outside the vacuum envelope and are matched to the input and output coaxial transmission lines. This type of coupler is capable of transferring most of the energy from the lines to the main helix, which is inside the vacuum envelope, without making physical contact with the helix. These "coupled helix matches" have the additional advantage of having very wideband transfer characteristic. Further, they are capable of presenting a standing-wave ratio to the coaxial transmission line of 1.5:1 or less.

SPECIFIC CHARACTERISTICS

In the following sections, various characteristic curves that are encountered in traveling-wave tube operation are discussed.

Helix Voltage vs Frequency. A helix is usually designed so that the "slow-waves" travel at a velocity in the range of 1/10 to 1/30 of the velocity of light. If the wave velocity is examined as a function of frequency, it is found that a helix has a general characteristic curve similar to that shown in Figure 2.

In region A, wave velocity varies as a function of frequency; in region B, wave velocity is essentially independent of frequency. A broadband amplifier is normally operated in region B – the "non-dispersive region."

As mentioned before, the electrons must travel at essentially the same velocity as the waves (synchronous velocity) in order to obtain the growing wave interaction. Since the velocity of the wave varies as a function of frequency, the velocity of the electrons must also be varied so that interaction is maintained. Inasmuch as the velocity of the electrons is determined by the voltage difference between the cathode and the helix, there is also a characteristic curve of synchronous helix voltage as a function of frequency (see Figure 2).

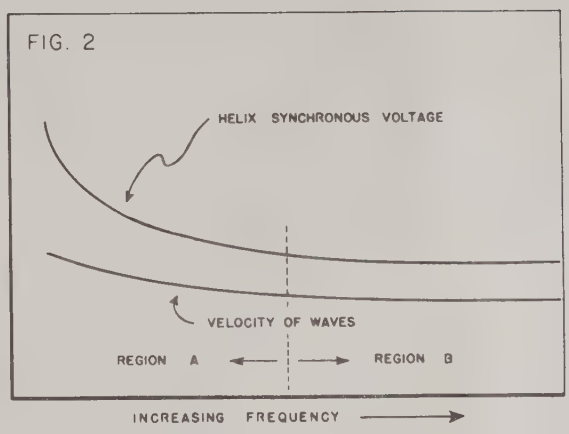

Figure 2. Phase Velocity of the Waves and Synchronous Helix Voltage as a Function of Frequency.

The reason a helix type traveling-wave tube can amplify over wide bandwidths without changing helix voltage can now be easily seen. In the non-dispersive region the synchronous voltage is essentially independent of frequency. That is, the helix voltage which gives the desired interaction between the waves and electrons can be fixed at one value, and this will be the correct value to provide interaction and amplification over a wide range of frequencies.

Gain vs Helix Voltage. To obtain the greatest interaction between the waves and the electrons, and thus the greatest amplification, the helix must be operated at synchronous voltage.

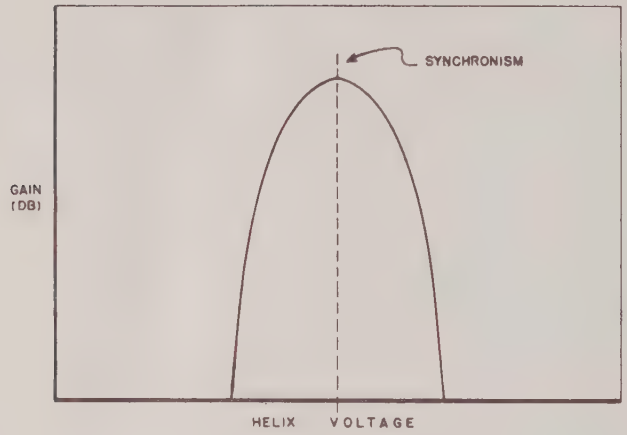

Figure 3. Gain as a Function of Helix Voltage.

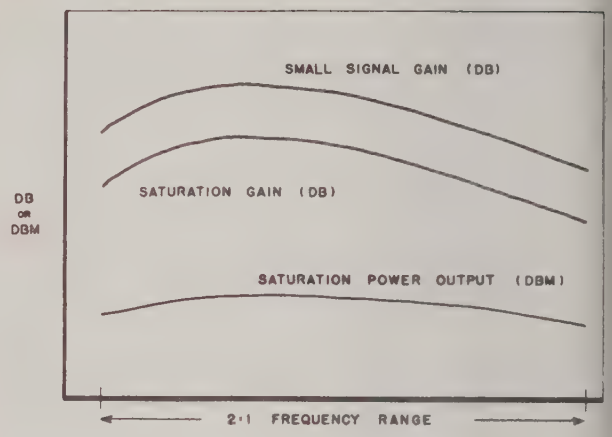

Figure 4. Gain and Power Output as a Function of Frequency.

Should the helix voltage be varied away from synchronism, the gain will decrease as shown by the curve in Figure 3. This characteristic of the TWT is parabolic in shape.

Gain and Power Output vs Frequency. Figure 4 shows a typical plot of gain vs frequency for a fixed value of helix voltage. Small-signal gain is obtained for all values of input signal level except those which drive the tube near its maximum or saturation power output. Saturation gain is the gain obtained when the tube is driven to its saturation power output level. It is seen that the gain and power output curves generally reach a maximum near the center of the band and droop off toward the band edges.

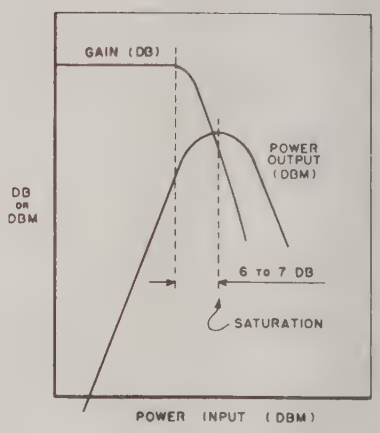

Figure 5. Gain and Power Output vs Power Input at a Fixed Frequency.

Power Output and Gain vs Power Input. Figure 5 shows the variation of power output and gain as a function of power input at a fixed frequency. The amplifier is linear until the power input is within 6 to 7 db of the value which drives the amplifier to saturation. At this point the power output curve begins to droop over, and gain of the tube begins to decrease. At saturation the power output is a maximum, and gain has decreased to the saturation gain level. As the tube is driven beyond saturation the power output drops off, and gain continues to decrease. To obtain maximum power output from an ordinary traveling-wave tube, the right amount of power input must be applied. As will be noted, the saturation region does not exhibit the leveling off or flat saturation characteristic that is found in conventional low frequency amplifier tubes.

Gain vs Beam Current and Grid Voltage. Figure 6 shows that the gain at any fixed frequency is essentially a function of the 1/3 power

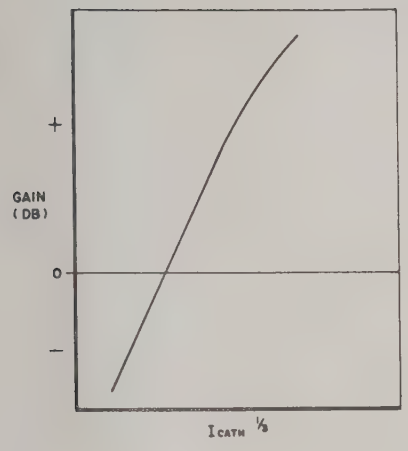

Figure 6. Gain vs Beam Current.

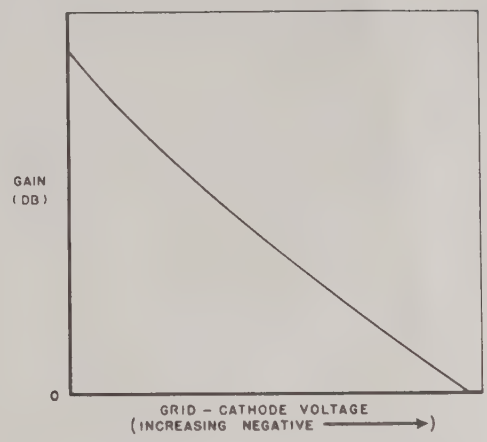

Figure 7. Gain vs Grid Voltage.

of the beam current, and as beam current decreases, gain decreases. Figure 7 shows that the gain of the tube decreases as the grid electrode is made negative with respect to the cathode. This results from the fact that operating the grid negative with respect to the cathode causes the beam current to decrease.

Should the beam current be decreased below a certain value as shown in Figure 6, the gain of the tube measured in db becomes negative, (i.e., the tube is acting as an attenuator). If the beam current is reduced to zero, the net "cold" attenuation of the tube is available. The total change in signal output level as beam current is decreased from its normal value to zero is equal to the sum of the net gain of the tube plus the cold attenuation. This can approach a variation in signal level of about 100 db. Such a change in signal output level is accomplished merely by varying the control grid voltage.

SPECIAL CHARACTERISTICS

Low Noise Amplifiers. A typical low power amplifier may exhibit a noise figure of 20 db. Certain applications require lower noise figures than this. Techniques are available in electron gun design whereby the "shot noise" in the beam can be "de-amplified" before it reaches the beginning of the helix. Special purpose tubes built in this fashion have reached noise figures as low as 6 db.

Narrow Band Amplifiers. Where an application does not require extremely wide bandwidths, tubes can be designed to operate in the dispersive region of the tube characteristic where the velocity of the waves varies as a function of frequency (see Figure 2). In this region, operation at a fixed voltage leads to amplification over only a relatively narrow band of frequencies. Extremely high values of gain (e.g., 60 to 70 db) can be obtained because the problem of controlling spurious oscillations is much simplified since the tube exhibits gain over only a relatively narrow band.

Special Gain Variation. Sometimes special requirements are imposed on the gain variation of the tube as a function of frequency. Tubes can be designed which exhibit an essentially constant value of gain across the band. Others have been built which have linearly increasing gain with frequency. Various other combinations are also possible.

HUGGINS LABORATORIES
ENGINEERING NOTES
VOL. I, NO. 2 JANUARY, 1955
Published by Huggins Laboratories Sunnyvale, California

MICROWAVE MEASUREMENT TECHNIQUES

L. A. Roberts *

As traveling-wave tubes come into more common use, the need becomes apparent for clarification of the various measurement techniques involved in evaluating tube characteristics. In such measurements emphasis must be placed upon broad-band, untuned measuring techniques and test equipment since the traveling-wave tube is a very broadband device. Otherwise, much time would be lost in the repetitive and laborious adjustment and tuning of narrow band devices to make point-by-point measurements across wide frequency ranges.

In this Engineering Note we will concern ourselves with the measurement of small-signal gain, power output, standing-wave ratio, insertion loss, and noise figure. Though automatic and more modern techniques may be available, the methods discussed herein will prove both useful and reliable. Further, these methods require commonly available and relatively inexpensive test equipment.

The types of broadband test equipment commonly used are:

1. Self-tracking tunable signal generator with calibrated power output.
2. Untuned coaxial crystal detector.
3. Untuned coaxial bolometer or thermistor mount with self-balancing power bridge.
4. Broadband coaxial fixed attentuator.
5. Coaxial switch (SPDT).
6. Coaxial slotted section (for VSWR measurements) with untuned detector.
7. Coaxial or waveguide directional coupler.
8. Flourescent noise source.

The emphasis on measuring equipment is placed upon coaxial systems. This is because coaxial test equipment has inherently wideband properties. Waveguide equipment is utilized only when equivalent coaxial equipment is not available or will not do an equivalent job.

SMALL-SIGNAL GAIN MEASUREMENT

A rapid and satisfactory method of measuring gain is to make an insertion gain measurement using the substitution method. This method requires no knowledge of the detector characteristics, nor is absolute power calibration of the signal generator necessary. Accuracy of the measurement depends only on the calibration accuracy of the signal generator output attenuator.

Figure 1 shows a block diagram of the small-signal gain measurement system. With the coaxial switches in position 1, the output of the sig-

* Formerly of Huggins Laboratories, Inc.

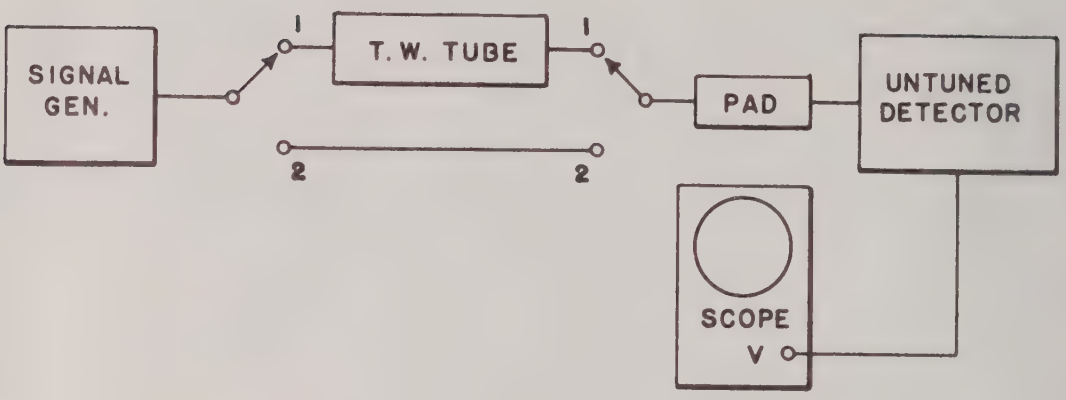

Figure 1. Block Diagram of Gain Measurement System.

nal generator (which has a matched 50 ohm output) is fed to the TWT input through a coaxial single-pole double-throw switch. The output of the TWT is in turn fed through another coaxial switch and a 6 db minimum coaxial fixed attenuator to the untuned detector (If the detector is matched to the coaxial switch, the pad can be eliminated). The detector output is then applied to the vertical deflection channel of an oscilloscope. When the switches are placed in position 2, the tube is by-passed.

Procedure. Apply pulse or square wave modulation to the signal generator. With the tube operating and the switches in position 1, the output attenuator of the signal generator is adjusted to give some convenient deflection on the scope. This is attenuator reading 1. The switches are then placed in position 2 and the attenuator readjusted to give the same deflection on the scope. This is attenuator reading 2. The insertion gain of the tube is then the difference between attenuator readings 1 and 2 measured in db.

Precautions. Both the signal generator and the detector must present good impedance matches as seen by the switch. If they are not matched, reflection losses can give up to several db error in gain. This is the reason for the pad ahead of the unmatched detector, for a 6 db pad guarantees a VSWR of at most 1.5:1.

Also, the switches used must have a low VSWR and very low crosstalk. Crosstalk is stray feedthrough from the input to output terminals of the DPST switch combination through the unused channel. The crosstalk ratio is measured with the TWT removed and is equal to the difference between the signal generator attenuator readings when it is adjusted for equal scope deflection with the switches in position 1 and 2. Regenerative feedback around the switches, which introduces errors in the gain measurement, will be prevented if the crosstalk ratio is at least 20 db greater than the gain of the tube being measured. If the crosstalk ratio exceeds 45 db, it probably cannot be measured with the system in Figure 1. The crosstalk ratio can be measured in such cases with the insertion loss measurement system soon to be described.

Further, care must be taken to insure that the output power level of the tube is at least 10 db below the saturation power level. This eliminates errors due to the decreasing gain characteristic of the traveling-wave tube in the region near saturation.

POWER OUTPUT MEASUREMENT

When making power measurements over wide frequency ranges, it is convenient to use broad-

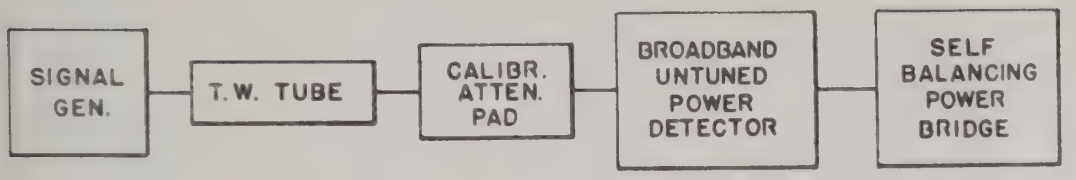

Figure 2. Block Diagram of Power Measuring System.

band (untuned) bolometer or thermistor mounts as power detectors. When these mounts are operated in conjunction with a self-balancing wattmeter bridge, they provide a convenient system for the measurement of absolute power.

If the power level to be measured is greater than the maximum allowable power input to the mount, a calibrated attenuator pad should be inserted ahead of the mount. The most convenient type of pad to use is the resistive film type which has attenuation characteristics that are essentially independent of frequency. Care must be taken not to exceed the maximum input rating of the attenuator.

If power levels to be measured are greater than the rated dissipation of standard attenuator pads, a directional coupler must be placed on the output of the tube. The main arm of the coupler is terminated with a broadband load, and the power detector, with appropriate pads, is placed in the auxiliary arm of the coupler. Broadband coaxial directional couplers with coupling ratios of 10 and 20 db from main arm to auxiliary arm are available.

Should gain measurements be made in conjunction with the power measurements, the power output of the signal generator must be calibrated using its power monitor at each frequency. For accuracy, the power output reading of the signal generator should be initially checked using the bolometer mount and the wattmeter bridge at least over the range of power levels that the bridge can accurately read. Small-signal gain measurements obtained with this equipment should check with the small-signal gain measurements made by the substitution method if the calibration of the attenuator pad and the signal generator is checked.

If all power measurements are recorded in terms of dbm (i.e., db with respect to one milliwatt), the readings of the power bridge, the attenuator (in db) and the signal generator need be merely added and subtracted to obtain power output and gain. Conveniently, most signal generators and power bridges are calibrated in dbm as well as milliwatts.

Figure 2 shows the block diagram of the power measurement system. The power output is given by the equation:

$$\text{Pout (dbm)} = \text{Pad Attenuation (db)} + \text{Ratio of Directional Coupler (db)} + \text{Power Bridge Reading (dbm)}$$

The gain of the tube is given by the equation:

$$\text{Gain (db)} = \text{Pout (dbm)} - \text{Pin from Signal Generator (dbm)}$$

The above gain measurement is valid for both small-signal gain and gain measured in the saturation region and beyond.

STANDING-WAVE RATIO OR REFLECTION COEFFICIENT MEASUREMENT

For direct measurement of voltage standing-wave ratio (VSWR), the coaxial slotted line is the

simplest method. It is essential to have an untuned detector on the slotted line, however, in order to speed up broadband measurements.

When it is necessary to examine the VSWR continuously over a wide frequency range, and where fast checks are required such as on production test setups, the slotted line type of measurement becomes prohibitively time consuming and laborious.

For such situations, the measurement of reflection coefficient through the use of directional couplers is recommended. Two directional couplers which are connected so that one gives an output proportional to the incident wave and the other an output proportional to the reflected wave from the load are used. These two outputs can be detected and compared with a ratiometer to give a direct reading of reflection coefficient. The reflection coefficient is then converted to equivalent VSWR if necessary. The greater the accuracy required in the measurement of reflection coefficient, the higher must be the directivity of the directional couplers. In waveguide, directivity greater than 40 db over the waveguide range can be obtained which allows measurement of reflection coefficient of 0.1 with an accuracy of ±.02. This means that a load VSWR of 1.2 will give an indicated reading between 1.15 and 1.25. A waveguide to coaxial transition can be used to adapt the reflectometer to coaxial systems, but residual reflection in the transition limits the accuracy at low VSWRs.

Once the initial calibration is performed in such a reflectometer system, it is only necessary to tune the signal generator across the frequency range and read the reflection coefficient values directly. An excellent detailed discussion of this method, its errors and limitations, is given in the Hewlett-Packard Journal, Volume 6, Number 1-2, Sept. - Oct., 1954.

Even faster measurements can be made when a swept oscillator is employed. Reflection coefficient can be displayed directly on a scope as a function of frequency, and the measurement can be made at a glance.

INSERTION LOSS MEASUREMENT

Measurement of insertion loss in the range of 40 to 100 db (e.g., cold loss measurement in a traveling-wave tube) over a wide range of frequencies is not uncommon. Such a measurement cannot be made with a 1 milliwatt signal generator and a broadband detector, for this type of system does not have the power levels, nor the sensitivity, to measure much more than 45 db insertion loss.

Wideband measurements can be made quickly and easily, however, with the use of one or two traveling-wave tubes as amplifiers. Use of a traveling-wave tube with a noise figure of 20 db ahead of the detector gives a sensitivity into a broadband detector on the order of –65 to –75 dbm. This alone allows insertion loss measurements of 65 to 75 db. Further, if the output of the signal generator is amplified to the power level of one watt (+ 30 dbm) by using a medium power traveling-wave tube, the total insertion loss then measurable becomes 95 to 105 db.

Since traveling-wave tubes are broadband, untuned devices, the only adjustment necessary in this system as frequency is changed across the band is the tuning of the signal generator. The insertion loss measurement is made in the same manner as the insertion gain measurement shown in Figure 1 except for the addition of the amplifiers before and after the switches. Commercially available switches, when connected as shown in Figure 1, have been measured which have a combined crosstalk ratio in excess of 120 db This, of course, eliminates any crosstalk error in insertion loss measurements in the range of 95 to 105 db.

NOISE FIGURE MEASUREMENT

When one is interested in measuring noise

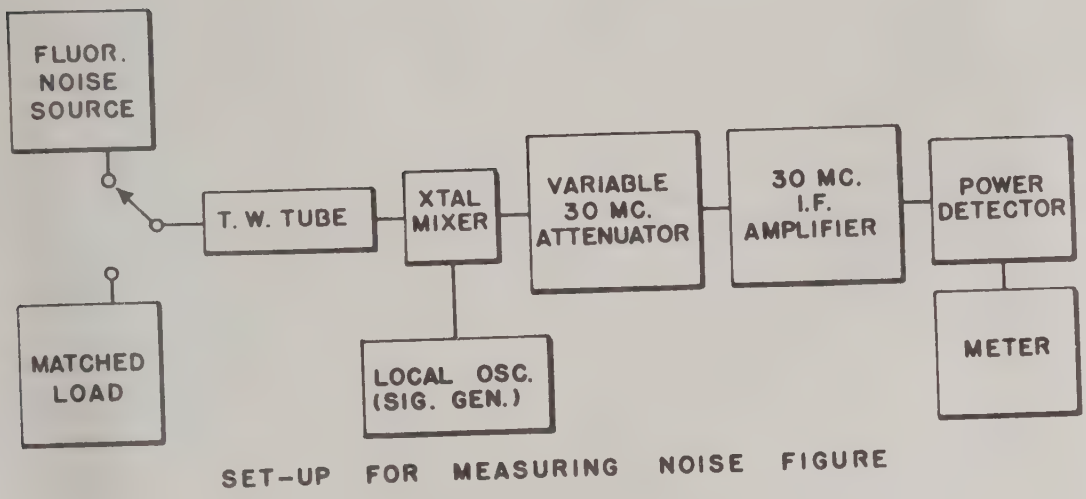

Figure 3. System for Measuring Noise Figure.

figure at a number of frequencies over a wide frequency band, a system which employs a fluorescent tube noise source and a superheterodyne receiver with a square-law second detector (i.e., a power detector) can be used. If noise figure does not vary too rapidly with frequency, a simple receiver can be used which employs an untuned crystal mixer, a local oscillator, a 30 mc IF strip, and a power detector. Note that no preselection or mixer tuning is used.

Without a preselector, the receiver will respond equally well to both the signal and image frequencies. With a 30 mc IF amplifier, these two frequencies will be only 60 mc apart. The measured noise figure will be an average of the true values at two frequencies 60 mc apart providing noise figure is not a rapid function of frequency. This is accurate enough for most purposes. If noise figure varies so rapidly that it will be appreciably different at two frequencies spaced 60 mc apart, then preselection is necessary.

The noise figure of an amplifier is defined as the ratio of the signal-to-noise ratio at the input of the amplifier to the signal-to-noise ratio at the output of the amplifier, That is,

$$F = \frac{(S/N)in}{(S/N)out} \qquad \text{(power ratio)}$$

When the measurement is made according to the method to be outlined, and a noise source whose level is 15.8 db above thermal noise is used, the above equation becomes:

$$F = \frac{37k}{\frac{P_1}{P_2} - 1} \qquad \text{(power ratio)} \qquad (1)$$

where, P_1 and P_2 are as defined in the measurement procedure below, and k, a number smaller than 1.0, is the cable loss in db between the noise source and the tube converted to a power ratio. (e.g., for cable loss = 1db, k = .794)

When a fluorescent noise source is used, it is not necessary to know the effective RF noise bandwidth of the receiver.

Procedure: The tube to be measured is connected into the system shown in Figure 3. The

power detector in the receiver may take the form of a bolometer or a thermistor operating into a self-balancing wattmeter bridge, or it may be a thermocouple whose output is connected to a microammeter.

With the TWT operating and the local oscillator tuned to the desired frequency, switch the tube input to the noise source. Adjust the variable 30 mc attenuator until the output meter indicates approximately full scale. This is reading P_1.

Then switch the tube input to the matched load. The output meter now indicates P_2. Insert the values of P_1 and P_2 in equation 1 and compute the noise figure. To determine the noise figure in db, merely convert this number to db.

Precautions: The accuracy of this measurement is based on the assumption that the receiver is linear. This will be true if the local oscillator signal is large enough to produce linear mixing and if the IF amplifier is operated in the linear portion of its characteristics.

The measurements should be taken quickly enough so that power meter drift will not effect readings.

SHIPMENT DAMAGE CLAIM

The instrument should be tested as soon as it is received. If it fails to operate properly or is damaged in any way, a claim must be filed with the carrier. Have carrier agent inspect damage to instrument and packing crate and forward us a copy of his written report. You will then be advised of replacement or repair arrangements and disposition of the equipment. Please include model number, type number and serial number when referring to this instrument for any reason.

WARRANTY

ALFRED products are warranted against defects in workmanship and materials. This warranty is limited to repair or replacement of products or parts (except tubes, transistors, and batteries) which prove defective within one year after delivery to original purchaser. ALFRED ELECTRONICS is not liable for consequential damage.

If any fault develops:

1. Notify us, giving full details of the difficulty, including the model number, type number and serial number. Upon receipt of this information you will be sent service instructions or shipping data.

2. Upon receipt of shipping instructions forward the instrument prepaid, and repairs will be made at the factory. If requested, an estimate of the charges will be made before the work begins when instrument is not covered by this warranty.

PACKING

The instrument should be packed in the original carton. If unusable or not available, use a wooden box with approximately three inches of excelsior or other shock-absorbing material surrounding the instrument. If desired, packing services of a local Transfer and Storage company may be employed.

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